



Industrial Shock Stabilization of Bakery Products: Technological Standardization of Freezing Regimes to Preserve Organoleptic and Rheological Characteristics

Mandzhgaladze Levan

MBA, Northeastern University (2019), Boston, MA, USA

Specialist degree, National Research Nuclear University MEPhI (2015), Moscow, Russia

Boston, USA

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Abstract— The paper addresses the preservation of quality in frozen bakery semi-finished products, a matter of growing scientific and technological importance given increased demand for highly ready-to-bake baked goods and the need to extend logistical chains within the Russian market. This study investigates the degradation of the rheological structure and sensory properties of laminated yeast-leavened products during conventional freezing. Industrial shock stabilization is achieved through a substantiated methodology of ultra-rapid cooling within the range of -35°C to -40°C . Using a production case study and laboratory monitoring data, it is demonstrated that technological standardization of freezing regimes minimizes damage to the gluten network by promoting the formation of a microcrystalline ice structure, thereby preserving the rheological properties and sensory characteristics of the finished product at levels comparable to freshly baked equivalents. The scientific novelty of the work lies in the development and industrial validation of adapted process sheets for laminated products. Practical process sheets and recommendations are provided to adapt shock-stabilization parameters to specific equipment, facilitating industrial implementation, subject to local validation and regulatory requirements. The practical significance of the research is the substantiation of a technology that can extend product shelf life by up to 6 months, thereby enabling wider distribution and greater assortment diversification. The results will be useful to food-production engineers and managers, cold-chain logistics specialists, and formulation developers (including manufacturers of cryoprotectants and dough improvers) interested in prolonging shelf life and expanding the geographic reach of ready-to-bake pastry products.

Keywords— shock freezing, laminated yeast-leavened dough, rheological properties, organoleptic characteristics, gluten network, ice crystallization, technological standardization.

I. INTRODUCTION

The contemporary market for bakery products in Russia is characterized by two key trends: a growing consumer demand for highly ready-to-bake products (bake-off technology) and the need for manufacturers to expand their supply geography, including into logistically complex, hard-to-reach regions [1]. The implementation of these strategic objectives is impossible without the use of long-term

storage technologies, among which freezing plays a leading role. However, despite its widespread use, freezing yeast-based products with complex structures, particularly laminated ones, poses significant technological challenges [2].

The scientific problem underpinning this study is the cascading degradation of the quality of laminated yeast-leavened dough when conventional (slow) freezing methods are used. The primary

damaging factor is the process of water crystallization. During slow cooling, large ice crystals (macrocrystals) form in the dough, mechanically rupturing the thin gluten strands that constitute the product's structural framework and damaging the yeast cell walls [3, 12]. This leads to irreversible consequences: reduced gas-retention capacity of the dough, loss of volume during baking, deterioration in crumb texture (staling, crumbliness), and, as a result, a sharp decline in the organoleptic attributes of the finished product [10].

Moreover, the initial freezing regime determines the product's subsequent stability during storage. A suboptimally formed ice structure is prone to recrystallization, growth of larger crystals at the expense of smaller ones, especially under the inevitable temperature fluctuations in the logistic chain, which aggravates structural damage [4].

The aim of the present study is the scientific substantiation and experimental confirmation of the effectiveness of an industrial shock-freezing methodology for preserving the initial rheological and organoleptic characteristics of laminated yeast-leavened products.

To achieve this aim, the following objectives were defined:

1. To analyze and systematize the parameters of the adapted technological scheme for the production of frozen laminated semi-finished products.
2. To investigate the influence of the shock-freezing regime (temperature from -35°C to -40°C) on physicochemical and microstructural transformations in the dough.
3. To carry out a quantitative analysis of product preservation based on production laboratory-control data (mass dynamics, baking loss, shrinkage).
4. To assess the organoleptic characteristics of the finished products and their conformity with regulatory requirements.
5. To determine the practical significance and potential risks associated with the implementation of the technology in the Russian market.

The scientific novelty lies in the first use of the shock-stabilization method for laminated yeast-leavened products in the domestic industry. The

method is based on adapted technological process sheets, which enable the product to maintain a quality comparable to that of the freshly prepared analog for up to 6 months, a considerably longer shelf life than existing methods.

II. MATERIALS AND METHODOLOGY

The research has an integrated character and is based on the synthesis of two methodological approaches: case study and systematic literature review. This design makes it possible, on the one hand, to examine a real technological process introduced into production and obtain empirical data on its effectiveness, and, on the other hand, to construct a theoretical framework for interpreting and explaining the observed phenomena.

As the case study object, the production site of JSC Vladimir Bread-Baking Plant was selected, where the technology of shock-freezing for laminated yeast-leavened products had been implemented and refined. The empirical basis of the research comprised internal technical and control documentation of the enterprise, including the following groups of sources:

- The technological scheme for the production of frozen, laminated yeast-leavened semi-finished products, and extracts from technological process sheets that regulate dough mixing parameters and baking conditions for finished products on the line.
- Laboratory-control reports on flour and pilot industrial bakes, recording raw-material parameters, process conditions, and quality characteristics of semi-finished and finished products at different stages (freezing, defrosting).
- The product specification (passport), contains normative organoleptic and physicochemical indicators, composition, nutritional value, storage conditions, and shelf life.
- Calculations of caloric content and nutritional value for different product types, detailing the component composition of dough and fillings.

The theoretical basis of the study consisted of scientific publications indexed in the international databases Scopus and Web of Science. The systematic literature review was focused on the following key areas: the rheological properties of frozen dough and

their modification under exposure to low temperatures; the impact of freezing-thawing processes on the microstructure of the gluten framework and the viability of yeast cells; physicochemical mechanisms of ice crystallization and recrystallization in food systems; and the role of functional food additives (cryoprotectants, hydrocolloids, emulsifiers) in the stabilization of frozen dough semi-finished products.

III. RESULTS AND DISCUSSION

Technological Standardization of the Production Cycle as the Basis for Quality Stability

Analysis of the production process demonstrated that the success of the shock-stabilization technology is determined not only by the freezing stage itself, but also by the strict standardization of all preceding operations. The adapted technological scheme (Fig. 1) includes a set of critical control points (CCPs) to prepare the dough for exposure to extreme temperatures.

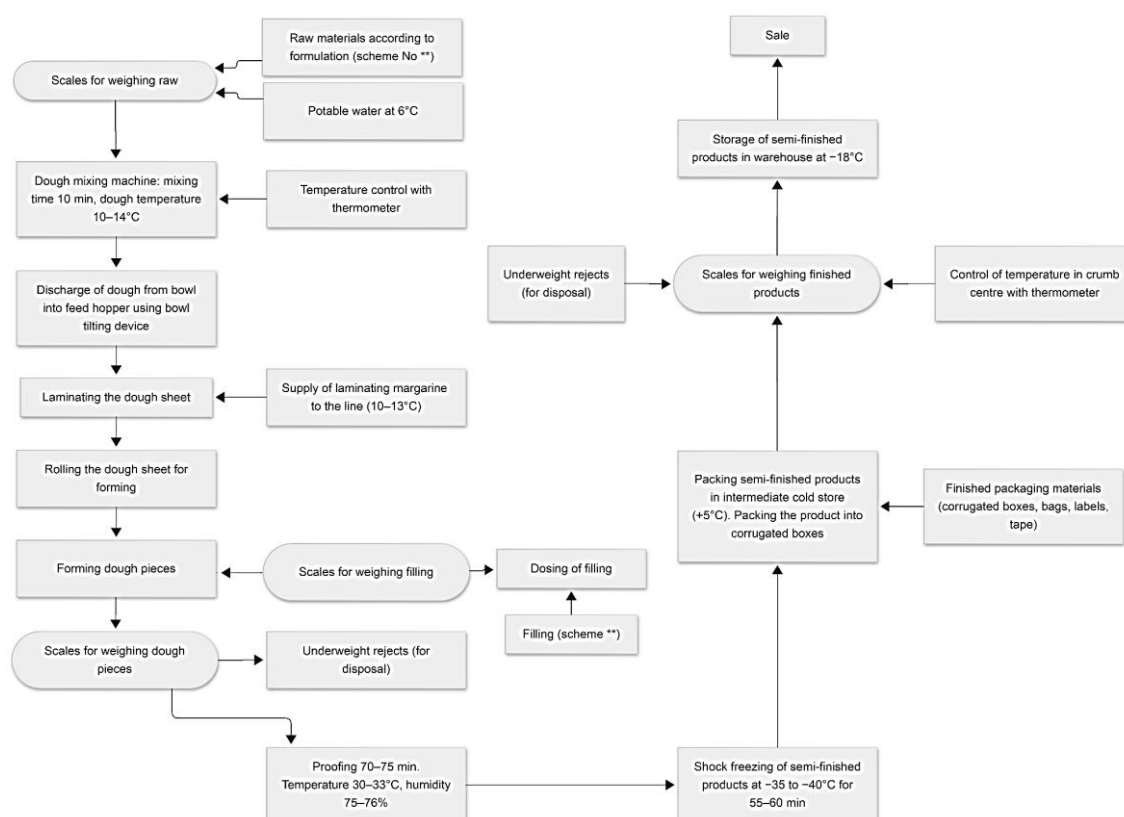


Fig. 1. Adapted technological scheme for the production of puff-yeast frozen semi-finished products

The key CCPs at the stages preceding freezing are the mixing parameters and dough temperature. According to the technological process sheets, the total mixing time is 10-13 minutes, and the final dough temperature is strictly controlled at 10-14 °C. Maintaining such a low temperature is a deliberate measure to inhibit the premature metabolic activity of yeast cells. Fermentation processes prior to freezing must be minimized to preserve the yeast's full gas-forming potential for the final proofing and baking stages, directly at the point of consumption. This approach fundamentally differentiates the technology

from classical breadmaking and underlies the high volume and open, porous crumb structure of the finished product after thawing [5].

The temperature of the laminating margarine (10-13 °C) is likewise standardized to ensure the formation of a distinct, continuous layered structure, which serves as the basis for the rheological behavior of this product category.

Physicochemical Foundations of Shock Freezing and Its Influence on Dough Microstructure

The central element of the technology is the shock-freezing regime: a chamber temperature range of -35°C to -40°C , with an exposure time of 55–60 minutes. This regime provides the maximum possible rate of heat removal and rapid passage through the cryoscopic point (the zone of most intensive crystallization).

The principal advantage of this approach lies in the mechanism of ice-phase formation. In contrast

to slow freezing, during which large, sharp-edged ice crystals have time to grow and destroy the structure, shock freezing promotes the simultaneous formation of an enormous number of crystallization nuclei. As a result, water in the dough transitions to the solid state as numerous small, rounded microcrystals [6, 13]. Such microcrystals do not cause significant mechanical damage to gluten strands or yeast cell membranes, thereby preserving the integrity of the dough's matrix structure, as conceptually illustrated in Fig. 2.

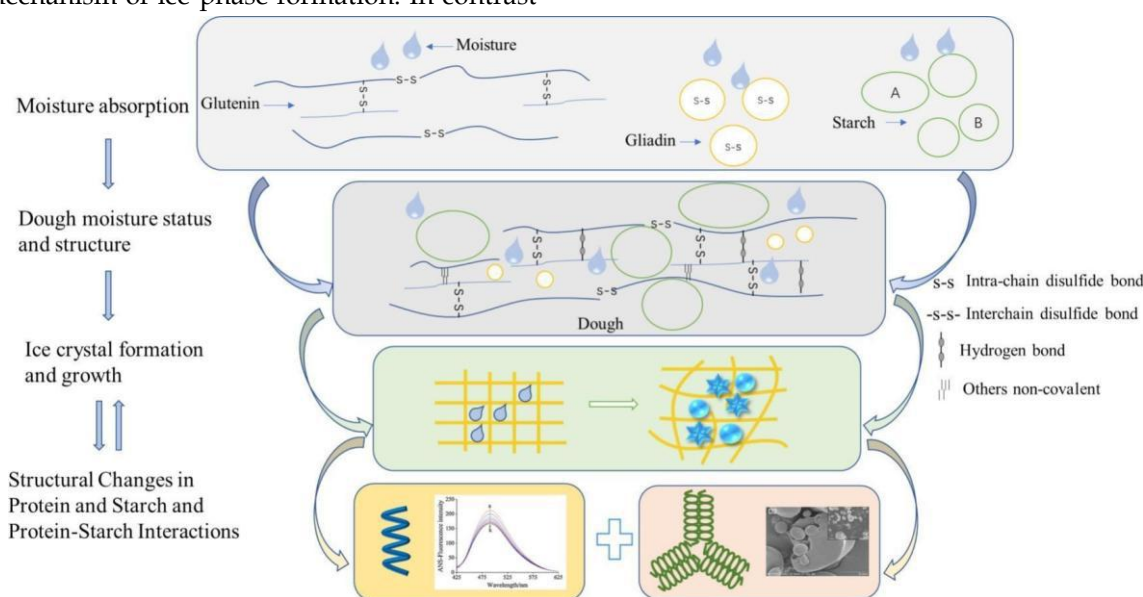


Fig. 2. Conceptual diagram of the influence of freezing rate on the microstructure and quality of laminated products [16]

However, even an ideally formed microcrystalline structure is thermodynamically unstable. Any temperature fluctuations during storage and transportation, which are inevitable under real operating conditions, trigger Ostwald ripening (recrystallization), during which small crystals dissolve, and their mass is transferred to larger ones, leading to their growth and the gradual degradation of structure [7, 14].

To counteract this phenomenon, the technology employs not only a physical but also a chemical approach. Recipe analysis reveals the presence of complex food additives, such as Improver Premium Frost. These components, which include hydrocolloids and emulsifiers, act as cryoprotectants. They bind part of the free water in the dough,

reducing its availability for crystallization, and increase the viscosity of the unfrozen phase (the cryoconcentrated solution), which physically slows diffusion processes and, hence, the rate of recrystallization [8, 15]. In this manner, system stability is ensured by the synergy between ultra-rapid cooling and chemical stabilization.

Quantitative Analysis of the Preservation of Rheological and Organoleptic Characteristics

The effectiveness of the developed technology is confirmed by production-control data. One of the key indicators of structural preservation is the mass dynamics of dough pieces during freezing (Table 1).

Table 1. Dynamics of the mass of dough pieces at the freezing stage according to production control data

Product	Average piece mass at forming, g	Average frozen piece mass, g	Mass change, g	Mass change, %
Homemade puff pastry with apple	96.8	93.7	-3.1	-3.20
French puff pastry with apricot	87.1	87.0	-0.1	-0.11
Puff pastry with apricot	86.1	86.1	0.0	0.00

The loss of mass upon freezing is very small, so there is no evidence of sublimation of moisture (i.e., freeze-drying). The rapid cooling of the product often forms an ice layer on its surface, which in turn creates a thin barrier to the escape of water from the interior. Retention of moisture during cooking is critical for maintaining the elasticity of the gluten network and the juiciness of the final product [11].

Other important indicators of structural integrity are baking losses. Laboratory-control data

for the defrosted product, Homemade puff pastry with apple, show a baking loss of 6.8% and a moisture loss (shrinkage) of 1.43%. These stable, moderate values indirectly confirm that the gluten network was not significantly damaged during freezing and storage, and that it effectively retains moisture and water vapor during thermal treatment.

The economic and technological viability of the process is confirmed by the analysis of finished-product yield shown in Table 2.

Table 2. Comparison of planned and actual output of finished products for different batches

Product	Planned yield (%)	Actual yield (%)	Deviation (absolute)	Deviation (%)
Homemade puff pastry with apple	280.00	280.78	0.78	0.279%
Puff pastry with apricot	200.00	207.93	7.93	3.965%
French puff pastry	220.00	250.20	30.20	13.727%
Homemade puff pastry (defrosted)	260.00	265.40	5.40	2.077%

As shown, in all analyzed cases, the actual product yield matches or exceeds the planned values. This demonstrates a high degree of control over the technological process and its production efficiency.

Ultimately, the technology's objective is to ensure high organoleptic quality. All laboratory-control reports presented contain the conclusion that complies with STO 00345458-9116/002-2007, and organoleptic indicators (appearance, color, taste, odor, consistency) are evaluated as complies or typical for this type of product. This is direct evidence that the final product obtained from semi-finished items frozen using the shock-stabilization technology is fully equivalent in quality to the fresh product described in the normative documentation.

The primary risk in implementing this technology is disruption of the cold chain during storage and transportation. As shown above, the stability of the product microstructure critically depends on maintaining a constant storage temperature ($-18\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$), as specified in the product passport. Significant temperature fluctuations may initiate ice recrystallization and nullify all advantages of shock freezing [9].

Several levels of protection are embedded in the investigated technology to mitigate this risk. First, a maximally stable initial structure is created. The use of shock freezing forms a system with minimal free energy, which is intrinsically more resistant to change. Second, chemical stabilization is employed. The use of complex improver-cryoprotectant systems raises the barrier to moisture migration and crystal growth.

Industrial Barriers, Risks, and Their Mitigation

Third, process control is emphasized. Strict adherence to all parameters in the technological process sheet results in a product with the maximum safety margin. Fourth, consumer guidance is provided. Clear instructions for defrosting (60–70 minutes at room temperature) and baking (220–230 °C, 20–23 minutes) at the final stage minimize the risk of improper preparation.

The practical significance of implementing this technology for the Russian market is substantial. A shelf life of 6 months at –18 °C eliminates geographical constraints, allowing deliveries to the most remote regions of the country. This not only expands the manufacturer's sales market but also provides residents of hard-to-reach territories with access to fresh, high-quality baked goods. In addition, the bake-off technology enables points of sale (cafés, shops, bakeries) to significantly expand their assortment without organizing a full production cycle, baking products as demand arises, and thereby optimizing operating costs.

IV. CONCLUSION

The conducted research enabled the following key conclusions to be formulated. The developed and industrially tested methodology, which includes strict standardization of dough-preparation parameters (in particular, maintaining a low temperature of 10–14 °C) and the application of an industrial shock-freezing regime (temperature from –35 °C to –40 °C for 55–60 minutes), is a highly effective tool for stabilizing and preserving the initial rheological and organoleptic characteristics of laminated yeast-leavened products.

The aim of the study was fully achieved. Based on an analysis of production data and the application of fundamental scientific concepts, it was demonstrated that this technology enables overcoming the key problem of degradation of the laminated dough structure during freezing. The principle for this protection is the formation of a microcrystalline ice structure, which limits damage to the gluten matrix and the viability of yeast cells. The mass balances, baking losses, shrinkage, product yield, and homogeneity have been quantitatively confirmed, and organoleptic tests have provided consistent results, indicating that the product is similar to a fresh-baked one.

The practical significance of the work is directly related to the Russian food industry. The proposed technology acts as a growth driver for the baking sector, enabling product shelf life to be extended up to 6 months. This opens new logistical opportunities for supplying remote regions and contributes to a substantial expansion and diversification of the range of fresh baked goods available to end consumers, thereby enhancing the competitiveness of enterprises in the market.

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